REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1995

3. REPORT TYPE AND DATES COVERED
Final Report (07-93 to 07-95)

4. TITLE AND SUBTITLE
The Development of a Prototype Expert System for Perioperative Nursing

5. FUNDING NUMBERS

6. AUTHOR(S)
LCDR M. Kimberley Lyons, NC, USN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Hospital
2080 Child Street
Jacksonville, Florida 32214

8. PERFORMING ORGANIZATION REPORT NUMBER
32-95

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Medical Department Center and School
BLDG 2841 HSHA MH US Army-Baylor University Grad Pgm in HCA
3151 Scott Road
Fort Sam Houston, Texas 78234-6135

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

19960911 018

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Early retirement initiatives have led to a shortfall of nurses and scarcity of expertise in the Navy Nurse Corps perioperative community. The Perioperative Nurse Training Course provides theoretical knowledge and basic technical skills, but does not prepare the novice to make clinical decisions. The purpose of this project was to develop and validate a prototype expert system suited to assist in the cognitive learning process of the novice perioperative nurse. While consulting the system, the novice will improve reasoning skills by modeling the decision style of experts. The prototype system was built using the 1st-Class Development System. Knowledge sources included one domain expert and AORN's 1995 Standards and Recommended Practices. Three independent experts validated the system. They rated their agreement with the design, content, interface, and outputs using a five-point Likert scale. The mean scores indicate that a prototype system that captures expert knowledge and provides a model of the expert's reasoning process can be developed and validated for perioperative nursing and may provide one solution to the problems created by the shortage of experienced perioperative nurses.

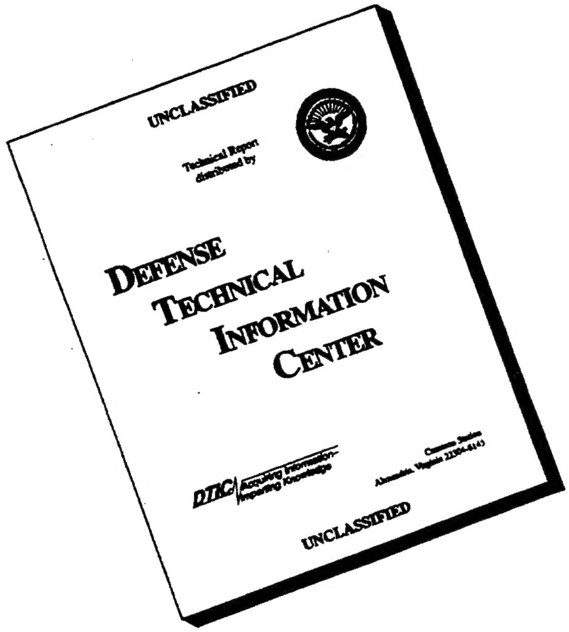
14. SUBJECT TERMS
artificial intelligence, expert system, perioperative nursing, operating room, decision making, reasoning skills

15. NUMBER OF PAGES
47

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
N/A	N/A	N/A	U/L

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

U. S. ARMY-BAYLOR UNIVERSITY

GRADUATE PROGRAM IN HEALTH CARE ADMINISTRATION

THE DEVELOPMENT OF A PROTOTYPE EXPERT SYSTEM FOR PERIOPERATIVE NURSING

A GRADUATE MANAGEMENT PROJECT

SUBMITTED TO THE FACULTY OF BAYLOR UNIVERSITY

IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF HEALTH ADMINISTRATION

BY

LCDR M. KIMBERLEY LYONS, NC, USN

JACKSONVILLE, FLORIDA

MAY 1995

ACKNOWLEDGMENTS

I wish to express my gratitude to the following individuals. First and most important, thanks to my preceptor, Captain William F. Lorenzen, Executive Officer, Naval Hospital Jacksonville, Florida for his continued support and guidance with this graduate management project and throughout my administrative residency. A very special thanks goes to Lieutenant Harold D. May for sitting through many hours of interviews explaining his reasoning methodology and testing and retesting the expert system. Lieutenant May's knowledge served as the basis for developing the expert system. My grateful appreciation to Ms. Bettye Stilley, the Naval Hospital's Medical Librarian, who patiently assisted me in obtaining many references. I also thank the three members of the expert panel: Commander Charles Dolan, Instructor, Perioperative Nurse Training Course; Lieutenant Commander John LaRue, Head, Perioperative Department; and Lieutenant Commander Renee Grosdidier, Education Coordinator, Perioperative Department, all of the Naval Hospital, Jacksonville, Florida. Each member validated the full prototype system and provided suggestions for improving the system. Finally, I thank my family. My husband, Ed, was understanding and patient about the time needed to develop the expert system and complete my graduate management project. Our daughter, Brie, will be happy to know that I'm finally leaving the computer and rejoining the family.

ABSTRACT

Early retirement initiatives have led to a shortfall of nurses and scarcity of expertise in the Navy Nurse Corps perioperative community. The Perioperative Nurse Training Course provides theoretical knowledge and basic technical skills, but does not prepare the novice to make clinical decisions. The purpose of this project was to develop and validate a prototype expert system suited to assist in the cognitive learning process of the novice perioperative nurse. While consulting the system, the novice will improve reasoning skills by modeling the decision style of experts. The prototype expert system was built using the 1st-Class Development System. Knowledge sources included one domain expert and AORN's 1995 Standards and Recommended Practices. The rules, relationships, and heuristics for the system were acquired through interviews with the domain expert. Example sets and rule trees were used to represent the knowledge. The user interface was designed as data entry screen that defaults to a menu-based interview when more explicit queries are needed. Three independent domain experts were asked to validate the system. They rated their agreement with the design, content, user interface, and outputs using a five-point Likert scale. The mean scores indicate that a prototype expert system that captures expert knowledge and provides a model of the expert's reasoning process can be developed and validated for perioperative nursing. This also suggests that expert systems could provide one solution to the problems created by the shortage of experienced perioperative nurses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Conditions That Prompted the Study

Like private and business industry, the Department of Defense (DoD) is restructuring and reducing the workforce to contain costs (Mundy and Gilcreast 1994). In October 1993, the Navy Medical Department was tasked to take a reduction in medical end strength of 534 officers and 1141 enlisted members. This end strength reduction will result in a loss of 199 Nurse Corps (NC) billets and thirty-nine Technical Nurse Warrant Officer (TNWO) billets (Hiatt 1994a).

At the end of fiscal year (FY) 1994, the Nurse Corps perioperative community already had an inventory shortfall of thirty nurses. Many losses were attributable to the early retirement initiatives that were implemented to facilitate the downsizing of the Navy Medical Department (Caffrey 1994b).

To prevent the perioperative nursing shortage from worsening, junior NC officers have been encouraged to seek this specialty (Caffrey 1994b). The junior nurses selected to enter the perioperative specialty are trained in the six-week Perioperative Nurse Training Course. The course was designed to provide NC officers the basic technical

skills necessary to function as a beginning level perioperative nurse (Caffrey 1992). Preliminary findings from the perioperative nurse satisfaction questionnaire distributed in August 1993 suggested that the course was too short and did not prepare the nurse to meet command expectations (Hiatt 1993; Hiatt 1994b).

Expert systems appear to have a future in nursing where solutions are needed to problems created by the shortage of experienced nurses. An expert system (ES) would provide a means of capturing and preserving the knowledge of retiring expert perioperative nurses. The information would be conveniently available to anyone that has access to a personal computer (PC) and could be used as a learning tool for novice perioperative nurses. Expert systems can also provide an understanding of how experts reason and thus help the novice and less expert nurses to improve their reasoning skills by modeling those of experts (Probst and Rush 1990; Petrucci and Petrucci 1991; Fonteyn and Grobe 1994).

Statement of the Problem

Early retirement initiatives have led to a shortfall of nurses and scarcity of expertise in the NC perioperative community. The Perioperative Nurse Training Course provides theoretical knowledge and basic technical skills, but does not prepare the novice to make clinical decisions. The management problem is to determine if an ES that captures expert knowledge and provides a model of the expert's

reasoning process can be developed and validated for perioperative nursing.

Literature Review

"An ES is a computer program that emulates the behavior of a human expert in a well-specified, narrowly defined domain of knowledge. It captures the knowledge and heuristics that an expert employs in a specific task" (Medsker and Liebowitz 1994). Expert systems can provide training to novices and improve the novice's reasoning skills. The system can also be used to capture scarce expertise, preserve knowledge, transfer expertise to remote locations, and act as a knowledgeable assistant for other experts (Turbain 1993).

History of Expert Systems

Expert systems arose in the mid-1960s with the construction of DENDRAL followed by MYCIN at Stanford University. The DENDRAL system was capable of identifying and naming chemical compounds from mass spectrometry data. MYCIN was capable of diagnosing and recommending treatment for infectious disease (Petrucci and Petrucci 1991). The development of DENDRAL led to the following conclusions:

> Human problem solvers are good only if they operate in a very narrow domain.
>
> Expert systems need to be constantly updated with new information. Such updating can be done efficiently with rule-based representation.

> The complexity of problems requires a considerable amount of knowledge about the problem area (Turbain 1993).

Several expert systems had begun to emerge by the mid 1970s and by the beginning of the 1980s ES technology appeared as commercial applications. Besides building expert systems, a substantial effort was made to develop tools to expedite construction. These tools became available in 1983, but required special hardware. In the late 1980s, development software became available that could run on personal computers (Turbain 1993).

Expert Systems in Nursing

Nurse researchers began exploring the development of expert systems in nursing in the early 1980s. The oldest working nurse ES is the Creighton Online Multiple Modular Expert System (COMMES). It was originally developed as an educational tool to teach nursing diagnosis and nursing care planning in the university environment. In 1990, it was sold to a private firm and marketed in the clinical setting as a stand alone, turnkey system (Lappe et al 1990; Probst and Rush 1990; Petrucci and Petrucci 1991; Fonteyn and Grobe 1994).

The Computer-Aided Nursing Diagnosis and Intervention system (CANDI) is a similar large scale system that was developed to aid nurses in formulating nursing diagnoses. The rule-based system was written in high level programming language known as Common LISP. CANDI runs on an IBM-AT

compatible microcomputer (Probst and Rush 1990; Petrucci and Petrucci 1991; Fonteyn and Grobe 1994).

Also written in Common LISP, the FLORENCE system advises on the identification of nursing diagnoses for a new client. FLORENCE applies case-based and model-based reasoning to care planning. The use of the multiple reasoning methods requires more time and greater development skill; however, the advantage is better simulation of the expert's reasoning process (Bradburn and Zeleznikow 1993).

The Expert system for Education in Nursing Diagnosis (EXTEND) is a computer assisted instruction package for teaching nursing diagnosis. EXTEND provides a knowledge base that can deduce a nursing diagnosis from case factors and provide diagnosis education to the student. The system was written using PROLOG, an artificial intelligence (AI) programming language, since no development shells were available to provide a low cost, PC-based environment for both rule processing and natural language dialogue. "An expert system shell, which allows the end user nurse educators to create their own client scenarios and natural language interface without requiring the skills of a professional software developer, should enable this program to be widely used" (Koch and McGovern 1993).

Until the late 1980s, expert systems had to be written using LISP, PROLOG, or another appropriate programming language. They attempted to cover broad domains rather than

well-specified, narrowly defined domains. These factors made ES construction difficult, expensive, and time consuming. The development of the ES shells and the shift to focus on concise nursing problems in a specific area of nursing have expedited the development and facilitated the growth of expert systems for use in nursing practice (Medsker and Liebowitz 1994; Fonteyn and Grobe 1994).

Three nursing systems that have already been developed using software shells are the Urological Nursing Information System (UNIS), CAREPLAN, and the Pressure sore risk Assessment and Wound Management EXpert system (PAWMEX). They are all prototype expert systems (Petrucci and Petrucci 1991; Woolley 1991).

UNIS was designed to help nurses perform patient assessments on elderly nursing home residents incontinent of urine. It was written in NEXPERT OBJECT, which is a rule-based, object-oriented software shell. Knowledge for UNIS was acquired from published nursing articles and from knowledge acquisition sessions conducted with expert nurses (Petrucci et al 1992).

CAREPLAN was developed for use in the obstetrical environment. The system was designed as a learning tool for students, newly graduated nurses, and experienced nurses with limited exposure to postpartum nursing. The software used for development of the ES was Personal Consultant Plus. This software is a rule-based system that allows for the

logical division of the knowledge base into frames. The knowledge engineer (KE) that developed the system was also the domain expert who provided the rules, relationships, and heuristics for the knowledge base (Probst and Rush 1990).

PAWMEX assists nurses in the decision making process required in pressure sore management. It was written in the WISEONE environment. WISEONE represents knowledge as a set of element definitions and a set of rules. Nursing literature on pressure sore management and product information were used as the sources of knowledge for PAWMEX (Woolley 1991).

Concepts of Expert Systems

Experts are individuals who possess expertise within a finite field or domain. They have an advanced level of skill and knowledge and perform their profession better than most others (Thompson, Ryan, and Kitzman 1990). Benner described five levels of nursing expertise using the Dreyfus Model of Skill Acquisition. The levels range from the novice, with a high reliance on theoretical knowledge, to the expert, with a high degree of experiential knowledge (Benner and Tanner 1987; Woolery 1990).

The objective in developing an ES is to transfer expertise from an expert to a computer and then to the user. This process involves four activities: knowledge acquisition, knowledge representation, knowledge inferencing, and transfer to the user (Turbain 1993).

Knowledge acquisition is often viewed as the most difficult part of creating an ES. It involves the collection, transfer, and transformation of problem-solving expertise from a knowledge source to a computer program for developing the knowledge base. Knowledge sources include domain experts, textbooks, research articles, and manuals (Chang and Hirsch 1991; Jones 1991; Turbain 1993).

Acquiring knowledge from domain experts is a complex task that frequently creates a bottleneck in ES development. Today, the state of the art requires a KE to capture the expertise of the human expert and then express it in a format that may be stored in the knowledge base. The information is usually acquired through interviewing techniques, scenario building, questionnaires, and protocol analysis (Ignizio 1991; Turbain 1993; Medsker and Liebowitz 1994).

After acquiring knowledge from the expert, the next step in developing an ES is to decide the knowledge representation approach. There are five major ways of representing knowledge in an ES: predicate calculus, production rules, frames, scripts, and semantic networks. Case-based reasoning and object-oriented programming are two additional methods of knowledge representation that are gaining interest (Medsker and Liebowitz 1994). The production rule or rule-based, frames, and object-oriented methods have been used in representing knowledge in nursing

expert systems developed using software shells (Probst and Rush 1990; Woolley 1991; Petrucci et al 1992).

The rule-based method is probably the most popular mode for knowledge representation in expert systems. Production rules are used for procedural representation and they take the form if-then, situation-action, or definitions. Rules are easily created from decision tables and trees. These are powerful tools for coding knowledge into a form to be executed by a rule-based shell. The rule-based method has been used extensively in expert systems, particularly for those constructed for diagnosis and planning (Carrico, Girard, and Jones 1989; Ignizio 1991; Medsker and Liebowitz 1994).

Inferencing is the process of drawing a conclusion by a set of rules and facts for a given situation. The inference engine serves as the inference or control structure for the ES. Three major strategies are incorporated in the inference engine to search for solutions: forward chaining, backward chaining, and a combination of forward and backward chaining (Ignizio 1991).

Forward chaining is event or data driven reasoning and is used for problem solving when data or basic ideas are a starting point. It is used in expert systems constructed for data analysis, design, and concept formulation. Goal directed reasoning or backward chaining entails having a goal or a hypothesis as a starting point and then working

backward to see if the conclusion is true. Diagnosis and planning expert systems employ backward chaining. A combination of forward and backward chaining allows bottom-up and top-down searching for different parts of the same problem (Medsker and Liebowitz 1994).

The dialogue structure serves as the language interface for knowledge transfer to the user. The user typically interacts with the ES in a consultative mode. The ES will initially request the user to enter observed conditions related to a situation. The system may request additional information after initial analysis. Also included is an explanation module that allows the user to challenge the ES and examine its reasoning process (Harding, Redmond and Corley 1993; Medsker and Liebowitz 1994).

Building and Implementing Expert Systems

The first phase in building expert system involves selecting the domain, defining the goal of the system, and identifying the sources of knowledge. Next the knowledge must be acquired to develop the knowledge base. Before acquiring the knowledge, however, the KE must be familiar with the domain (Prerau 1990; Medsker and Liebowitz 1994). By reading associated literature and manuals, and observing domain experts, the KE can gain a fundamental background on which his knowledge of the domain will be based. The KE needs this background to ask appropriate questions and to

understand what the expert is saying (Medsker and Liebowitz 1994).

After the knowledge is acquired, it is represented and encoded. Knowledge encoding entails programming the expert system, typically using an expert system shell or programming language. An ES shell contains the knowledge representation scheme, inference engine and dialogue structure. The knowledge base must be inserted into the architecture to form the complete expert system (Ignizio 1991; Medsker and Liebowitz 1994).

Building the knowledge base involves a process called rapid prototyping. This procedure requires the KE to build a little and test a little until the knowledge base is refined to meet the expected acceptance rate and users' needs. Expert system development is an iterative process where, after testing, knowledge is reacquired, represented, encoded, and tested again until the knowledge base is refined (Turbain 1993; Medsker and Liebowitz 1994).

System evaluation is the last phase in building the ES. System evaluation can be divided into two components: validation and verification. "Validation refers to determining whether the right system was built, that is, whether the system does what it was meant to do and at an acceptable level of accuracy" (Prerau 1990). It involves confirming that the expert system performs the desired task with a sufficient level of expertise. Validity can be

confirmed by other experts currently working in the problem domain. Validation using independent experts reduces the potential for bias in the results and lends credibility to the validation process (Prerau 1990; Medsker and Liebowitz 1994).

"Verification refers to determining whether the system was built right, that is, whether the system implementation correctly corresponds to its specifications" (Prerau 1990). It requires confirming that the program accurately implements the acquired expert knowledge. Automated rule-checking systems are available with some software shells. Also, when using software shells, the shell and its inference engine usually have a proven record of reliability and support (Prerau 1990; Medsker and Liebowitz 1994).

Three milestones are commonly used in expert system development: (1) a demonstration system or initial prototype, (2) a validation system or full prototype, and (3) a certified or production system. The demonstration system implements a subset of a problem. It allows the developer to determine the feasibility of the using expert system technology for the application, gives an idea of what the final system will look like, and provides the first system that can be tested (Prerau 1990; Koch and McGovern 1993).

Based on the results of testing and feedback from independent experts and potential users, the leaders of the

project must decide whether to continue development of the system. If the results and feedback are positive the validation system is developed. When the full prototype is near completion, field tests and review by outside experts are arranged (Prerau 1990; Koch and McGovern 1993).

The final milestone is a production system certified by experts as performing correctly at expert level, with complete documentation and a robust interface. The decision to develop a production version is based on the results of field tests of the prototype system; feedback from outside experts, potential users, and management; and estimates of the cost versus benefit of the final system (Prerau 1990; Koch and McGovern 1993).

After building the production system, there are various obstacles that may have to be faced before implementing the system. These obstacles include resistance to change, reluctance to use the computer system, the expert's fear of losing competitive advantage, and a system that is unusable because it is not current (Medsker and Liebowitz 1994).

Resistance to change can be overcome by incorporating users' comments into the development process. Also, if the system is properly evaluated and found to perform at the level of an expert, then confidence in using the system will increase (Medsker and Liebowitz 1994).

Training sessions and knowledge engineering consulting can reduce the reluctance to use the ES. If an ES shell is

used, the vendor may provide training, documentation, a hot line, and knowledge engineering consulting (Medsker and Liebowitz 1994).

The expert's fear of being replaced by the system or losing competitive advantage must also be addressed. This obstacle can be eliminated by recognizing that the expert will now have time to tackle other projects of interest (Medsker and Liebowitz 1994).

The last obstacle, not keeping the system current, is remedied by designating an individual or team to maintain the system. In most applications the knowledge base is dynamic and needs to be constantly updated. The knowledge base should be designed for easy maintenance to ensure its continued use (Medsker and Liebowitz 1994).

Rationale for Expert Systems in Nursing

The practice of nursing requires cognitive knowledge, decision making skills, technical skills, and interpersonal skills. These skills are enhanced by experience within a specific area or domain (Probst and Rush 1990).

An ES can be used as an alternate teaching tool to augment traditional learning strategies. Expert systems may enhance the acquisition and application of cognitive knowledge related to specific areas of nursing practice. Additional benefit may be gained because the computer based expert system can provide an environment conducive to learning without the fear of personal failure or endangering

the patient's welfare (Probst and Rush 1990; Thiele et al 1991).

"The implications for expert systems development are to model expert behavior by focusing only on those few parameters which are relevant to the decision making process" (Probst and Rush 1990). These parameters must be logically defined to model the decision path of the expert. The rules that are defined during the knowledge acquisition process then link the parameters to form decisions. During the consultation process, the novice nurse learns and can then model the decision style of the expert (Probst and Rush 1990).

The expert system must be viewed as only one component of the education process of the novice nurse. Demonstration and evaluated practice must be combined with the expert system learning experience to ensure the acquisition of technical and interpersonal skills (Probst and Rush 1990).

Purpose

The purpose of this project is to develop and validate a prototype expert system suited to assist in the cognitive learning process of the novice perioperative nurse. While consulting the system, the novice will improve reasoning skills by modeling the decision style of experts.

CHAPTER 2

METHODS AND PROCEDURES

Decision Environment

The ES was developed at a mid-sized Naval Hospital (NH). The NH is an eighty-five bed facility that supports eighteen medical and surgical departments and eight branch medical clinics. The hospital is home to one of Navy's five family practice residency programs and one of the Navy's two Perioperative Nurse Training Courses. The perioperative department is currently providing a course to train labor and delivery nurses to circulate Cesarean Section procedures.

The perioperative department performed approximately 3600 cases in FY94. The department consists of five operating rooms and is staffed by fourteen nurses.

The Association of Operating Room Nurses (AORN) defines the perioperative nurse as:

> the registered nurse who, using the nursing process, designs, coordinates, and delivers care to meet the identified needs of patients whose protective reflexes or self-care abilities are potentially compromised because they are having operative or other invasive procedures. Perioperative nurses possess and apply knowledge of the procedure and the patient's intraoperative experience throughout the patient's care continuum. The perioperative nurse assesses, diagnoses, plans, intervenes, and evaluates the outcome of interventions based on criteria that support a standard of care targeted toward this specific population (Avery 1994).

Perioperative nurses perform nursing activities in the preoperative, intraoperative, and postoperative phases of the patient's surgical experience. "Registered nurses enter perioperative nursing practice at a beginning level depending on their expertise and competency to practice. As they gain knowledge and skills, they progress on a continuum to an advanced level of practice" (Association of Operating Room Nurses 1994).

Registered nurses entering the NC perioperative community are assigned the 1950 subspecialty code. The suffix attached to the code states the level of education or experience in the subspecialty. Nurses completing the Perioperative Nurse Training Course, entry level nurses, are assigned the 1950V subspecialty code and suffix. Additional suffixes that are assigned to the code include: (1) E - BSN plus one year experience, (2) U - educational preparation less than a BSN plus one year experience, (3) K - certified by the National Certification Board: Perioperative Nursing, Inc. (NCB:PNI), (4) P - master degree in perioperative nursing, (5) S - four years (significant) perioperative experience, (6) T - currently working toward a master degree in perioperative nursing (Bureau of Medicine and Surgery 1992; Turner 1994).

Verification of the 1950 subspecialty code was completed in January 1994 (Beeby 1994; Caffrey 1994a). Four certified perioperative nurses, five nurses with significant

perioperative experience, and five entry level perioperative nurses are assigned to the Naval Hospital.

Sources of Knowledge

Knowledge sources for the expert system included AORN's 1995 Standards and Recommended Practices and one domain expert assigned to the perioperative department. The recommended practices represent AORN's official position on questions of aseptic and technical practice performed by perioperative nurses. They are based on the principles of microbiology, scientific literature, research, and the opinions of experts and present what the nurse should do in the ideal situation. The recommended practices are periodically updated to reflect research data and advanced technology (Association of Operating Room Nurses 1995).

The domain expert is a certified perioperative nurse. He has eight years of military and eight years of civilian perioperative experience. He is recognized as a domain expert by his subordinates, peers, and superiors.

The KE is also an experienced perioperative nurse, but is currently not practicing in the perioperative setting. The KE has six years of clinical and administrative perioperative experience.

Development Process

Knowledge Acquisition

The rules, relationships, and heuristics for the ES

were acquired through interviews with domain expert. The initial meeting was structured to provide an overview of expert systems and the scope of the project. An introductory article, a copy of the project proposal and a guided tour of an expert system and a commercially available tax advisor were provided. Copies of the project proposal were also given to the Head, Perioperative Department and the Perioperative Nurse Training Course Instructor.

To create the knowledge base, commonly occurring problems encountered by novice perioperative nurses were identified by the domain expert and KE. This led to the identification of five areas where factual and heuristic knowledge play a role in the perioperative nurses' reasoning process. At each knowledge acquisition meeting, the KE began by asking the first question or building a scenario to stimulate an initial response followed by introspective detailing by the domain expert. The KE also prompted the expert by interjecting "what-ifs?" and probing for the expert's reasoning process in making the decision. During the interviews, the knowledge was documented as if-then rules and decision trees when possible. At the end of the session, the knowledge was reviewed by the KE and expert and revised as needed.

Development Tools

After the acquiring knowledge from the expert the knowledge representation approach was selected. In the

interviews, the domain expert expressed the knowledge in if-then or situation-action statements. Perioperative nursing can be data driven and goal directed, so a rule-based software shell that would employ forward and backward chaining was selected for system development. Other criteria considered when selecting the tool included: a price range of less than 800 dollars, upwardly compatible modules or single-user PC development versions, a runtime license to distribute the system, an on-line tutorial, and debugging facilities.

The software chosen for the development of the expert system was the 1st-Class Development System, a product of Trinzic Corporation. 1st-Class is a menu-based system that lets the developer represent knowledge as example sets or rule trees. The system generates decision trees from examples given in spreadsheet form or rules can be individually built in graphical form on the screen. Knowledge is stored in knowledge base modules that can be chained with forward and backward chaining to form a large expert system (Gevarter 1990; AICorp, Inc. 1990).

Several algorithms are available for induction. The system can match queries to examples that exist in the knowledge base modules, generate rule trees, or use the rule trees constructed by the developer. Figure 1 is the menu that lists the methods available to build the rule. The

optimize method for rule building chooses the best order for the questions (Gevarter 1990; AICorp, Inc. 1990).

```
<┘for methods menu,  ICO,  ?,  Test,  Save,  Advisor
        Files   Definitions   Examples   Methods   Rule   Advisor
[F1=Help]       File = FLASH3                         [F9=Examples] [F10=Rule]


    Select a method to build the rule:      (Previous rule was exhaustive.)


       O = Optimize the rule
       L = Left-to-right optimized rule
       P = Progression of factors, left-to-right rule
       X = eXhaustive left-to-right rule
       M = Match the advisor responses against the examples
       C = Customize the rule with the rule editor


Factors:      5     Active Factors:     4
Examples:    16     Active Examples:   16     ? as response:     0
Results:      4     Lines in Rule:     46     Inference cutoff: 0

Numeric values are: Domains               alt-Trace off    Debug off

Report generation: on     Extend previous report: no      Brief: no
```

Fig. 1. Methods menu for building the rule.

The system consists of a developer and user interface. The developer interface contains on-line help, on-line tutorials, and four editor facilities: the spreadsheet editor enables the KE to edit example sets, the graphic editor allows the KE to edit decision trees, the text editor permits the KE to generate questions, answers, and data entry screens, and the hypertext editor helps the KE build hypertext files (AICorp, Inc. 1990).

The user can interact with the system through menus or data entry forms. The Hypertext and Hypergraphics

facilities and windows are used to guide and clarify the system for the user (AICorp, Inc. 1990).

The software shell also provides the following interactive tools to facilitate verification and validation: trace files, roadmap utilities, and debugging aids. With the tools the developer can discover errors, track the development of large systems, make changes in the rules and develop and maintain systems (AICorp, Inc. 1990).

Hardware used for the project were a Zenith 80486 twenty-five megahertz personal computer with four megabytes of RAM, superVGA color video monitor, mouse, and dot matrix printer with graphics capability.

Knowledge Coding

Knowledge coding was accomplished using the rapid prototyping approach. AORN's recommended practice for flash (steam) sterilization was used to form the basis of an initial knowledge base module (KBM). The first step in developing KBMs in 1st-Class is to define the possible results and attributes or factors. Choices or values are then entered for each factor. Based on table 1, the results, factors, and values were defined (see figure 2). An additional factor, REQUIRED, was added to provide advice on the best flash sterilizer to be used in an urgent situation.

TABLE 1

EXAMPLE OF MINIMUM EXPOSURE TIMES

Type of sterilizer	Type of Load	Temperature	Cycle Time
Gravity	Metal; nonporous items, no lumens	270 F (132 C)	3 minutes
	Metal with lumens, porous items (eg, rubber, plastic) sterilized together	270 F (132 C)	10 minutes
Prevacuum	Metal; nonporous items, no lumens	270 F (132 C)	3 minutes
	Metal with lumens, porous items, sterilized together	270 F (132 C)	4 minutes

Source: Association of Operating Room Nurses, 1995 Standards and Recommended Practices, (Denver: Association of Operating Room Nurses, Inc., 1995), 269.

```
Factor, Values, Text, Change, Activate, Move, Delete, Goto_chain, Return
         Files    Definitions    Examples    Methods    Rule   Advisor
[F1=Help]        5 Factors in FLASH3                     [F9=Files][F10=Examples]
        (inactive)                                                     weights-->
         MEMO       MAINFLASH   AUTOCLAVE    LOAD       REQUIRED    CYCLE
                    continue    gravity      single     next_case   grav3
                                pre_vacuum   multi      ASAP        prevac3
                                both         porous                 prevac4
                                             lumens                 grav10

                                             Complete the definitions, then
                                             press F10 to enter some examples.

                                             For more help, press F1.
```

Fig 2. Definitions screen

The example-based or decision table method was used to represent the knowledge. An example set (figure 3) was built by declaring the relationships between the situations and actions. If the factor was irrelevant in influencing the result, the [*] symbol was placed in the cell.

Example, Replicate, Change, Activate, Move, Delete
Files Definitions Examples Methods Rule Advisor
[F1=Help] 16 Examples in FLASH3 [F9=Definitions] [F10=Methods]

	(inactive) MEMO	MAINFLASH	AUTOCLAVE	LOAD	REQUIRED	weights--> CYCLE
1:		*	gravity	single	*	grav3
2:		*	pre_vacuum	single	*	prevac3
3:		*	both	single	*	prevac3
4:		*	both	single	*	grav3
5:		*	gravity	multi	*	grav10
6:		*	pre_vacuum	multi	*	prevac4
7:		*	both	multi	*	prevac4
8:		*	both	multi	next_case	grav10
9:		*	gravity	porous	*	grav10
10:		*	pre_vacuum	porous	*	prevac4
11:		*	both	porous	*	prevac4
12:		*	both	porous	next_case	grav10
13:		*	gravity	lumens	*	grav10
14:		*	pre_vacuum	lumens	*	prevac4
15:		*	both	lumens	*	prevac4
16:		*	both	lumens	next_case	grav10

Fig. 3. Examples screen

The rule was initially built using the optimize induction method, but later had to be changed to the exhaustive method to include the factor, MAINFLASH, that contained the text for the data entry form (see figure 4). The exhaustive method builds the rule so that all factors appear in the rule.

```
Edit, Mark, Print, Import, Stats, Text, Goto_Chain, Return
      Files  Definitions  Examples  Methods  Rule  Advisor
[F1=Help]      File = FLASH3                 [F9=Methods] [F10=Advisor]
MEMO                                                   Values---Results
MAINFLASH??
 └AUTOCLAVE??
   ├gravity:LOAD??
   │        ├single:REQUIRED??
   │        │       ├next_case:--------------------- grav3
   │        │       └ASAP:-------------------------- grav3
   │        ├multi:REQUIRED??
   │        │       ├next_case:--------------------- grav10
   │        │       └ASAP:-------------------------- grav10
   │        ├porous:REQUIRED??
   │        │       ├next_case:--------------------- grav10
   │        │       └ASAP:-------------------------- grav10
   │        └lumens:REQUIRED??
   │                ├next_case:--------------------- grav10
   │                └ASAP:-------------------------- grav10
   ├pre_vacuum;LOAD??
   │          ├single:REQUIRED??
   │          │       ├next_case:------------------- prevac3
   │          │       └ASAP:------------------------ prevac3
   │          ├multi:REQUIRED??
   │          │       ├next_case:------------------- prevac4
   │          │       └ASAP:------------------------ prevac4
   │          ├porous:REQUIRED??
   │          │       ├next_case:------------------- prevac4
   │          │       └ASAP:------------------------ prevac4
   │          └lumens:REQUIRED??
   │                  ├next_case:------------------- prevac4
   │                  └ASAP:------------------------ prevac4
   └both:LOAD??
        ├single:REQUIRED??
        │       ├next_case:------------------------- grav3
        │       │          &------------------------ prevac3
        │       └ASAP:------------------------------ grav3
        │                  &------------------------ prevac3
        ├multi:REQUIRED??
        │       ├next_case:------------------------- prevac4
        │       │          &------------------------ grav10
        │       └ASAP:------------------------------ prevac4
        ├porous:REQUIRED??
        │       ├next_case:------------------------- prevac4
        │       │          &------------------------ grav10
        │       └ASAP:------------------------------ prevac4
        └lumens:REQUIRED??
                ├next_case:------------------------- prevac4
                │          &------------------------ grav10
                └ASAP:------------------------------ prevac4
 ---- end of rule ----
```

Fig. 4. Rule screen

After testing the rule for accuracy, the advisor text for the factors, values, and results was entered. The text in the advisor was displayed in five ways: preface text,

question text, choice text, advice preface text, and advice text. Also, the hypertext windows were developed for on-line instructions (figure 5) and to display the AORN recommended practice for the user.

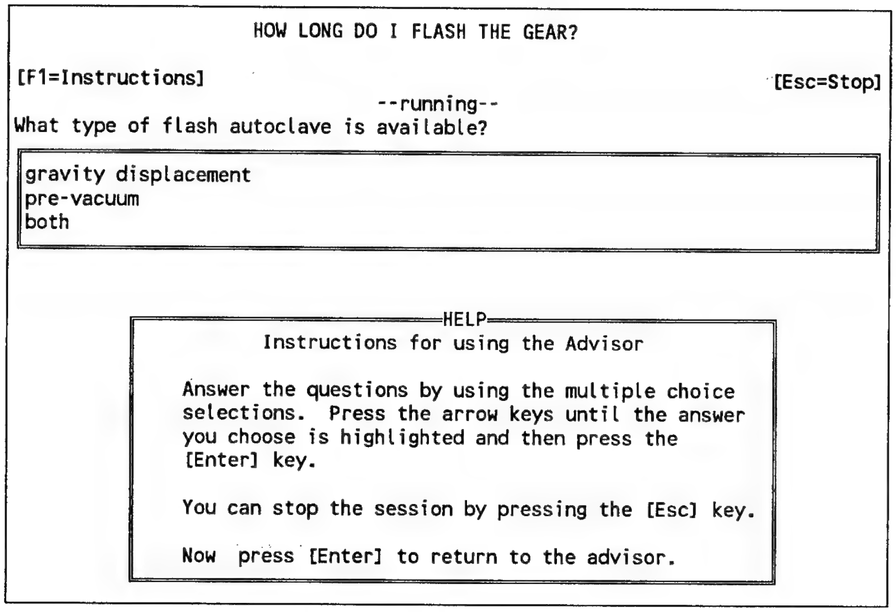


Fig. 5. Menu-based screen with hypertext on-line instructions

The KBM was then tested by the KE and domain expert. The text and the format for answering the questions were changed. The menu-based interface for selecting choices was changed to a data entry interface. Selections for the data entry fields were developed using the hypertext facility (figure 6).

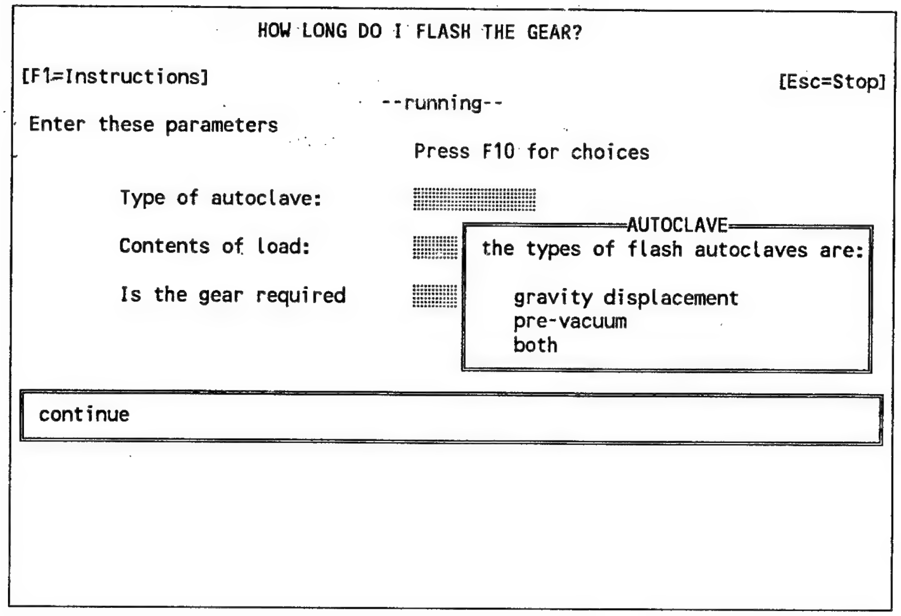


Fig. 6. Data entry screen with hypertext

Additional knowledge base modules were constructed using the example-based method. The induction algorithms were used to build the rules or to match the user responses to the example set.

Structure of the System

The Operating Room Advisor is composed of five sections. The root KBM, MAINMENU, is the selector using one factor with values representing each section. Each result is a forward chain to a KBM that begins one of the sessions. Figure 7 illustrates the roadmap utility and figure 8 displays the introduction screen for the advisor.

```
Return to Files screen, Print the map, <┘to see the KB
from any KB, backward chains are ┌above, forward chains are└below.
                    1st-CLASS RoadMap

MAINMENU
    ├GENERAL
    ├POSITION
    ├ESU3
    ├FLASH3
    └BREAK3
```

Fig. 7. RoadMap utility

```
                    U.S ARMY - BAYLOR UNIVERSITY
                OPERATING ROOM ADVISOR - VERSION 1.1
[F1=Instructions]                                          [Esc=Stop]

      Welcome to the U.S. Army - Baylor University Operating Room
Advisor.  This system incorporates factual and heuristic (rule of thumb)
perioperative knowledge and was designed to assist novice perioperative
nurses in developing reasoning skills.  The system can also be used by the
experienced perioperative nurse to review basic operating room techniques.
Select the area that you would like to review from the list below.

Is the room ready?
Are positioning aids needed?
Do I have the equipment needed for electrosurgery?
How long do I flash the gear?
Is the gear sterile?
Exit the advisor
```

Fig. 8. Introduction screen

Each section opens with an introductory screen that identifies the advisor and its purpose. After reading the screen, the user selects [continue] to advance to the data entry screen. The user is prompted in the instructions to complete the screen or to select [End] to by-pass the screen and move to the interview session (figure 9). At the end of each session advice is provided. The user can replay the session, start a new session, or quit the advisor (figure 10).

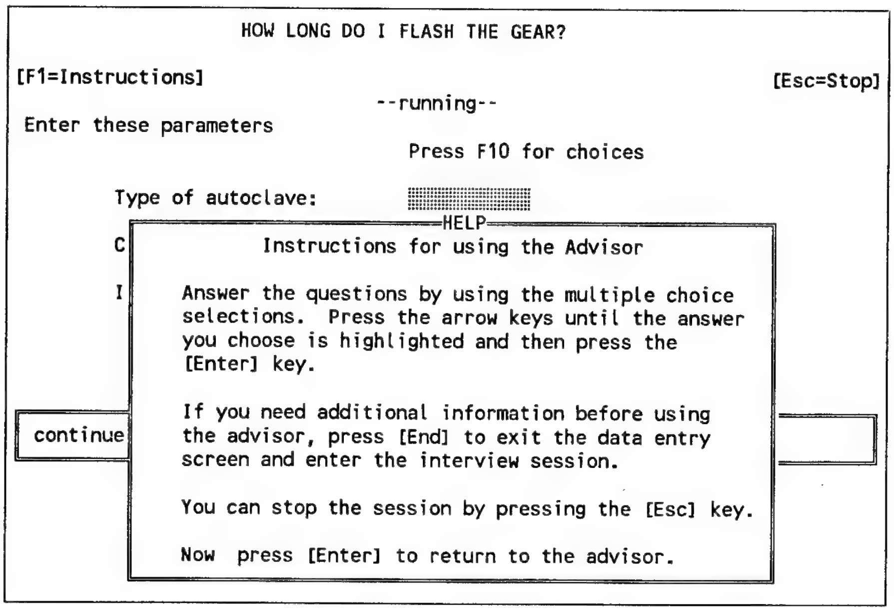


Fig. 9. Data entry instructions

System Verification and Validation

The 1st-Class shell facilitates system verification and validation through the use of small knowledge base modules and interactive tools. The rapid prototyping method build a

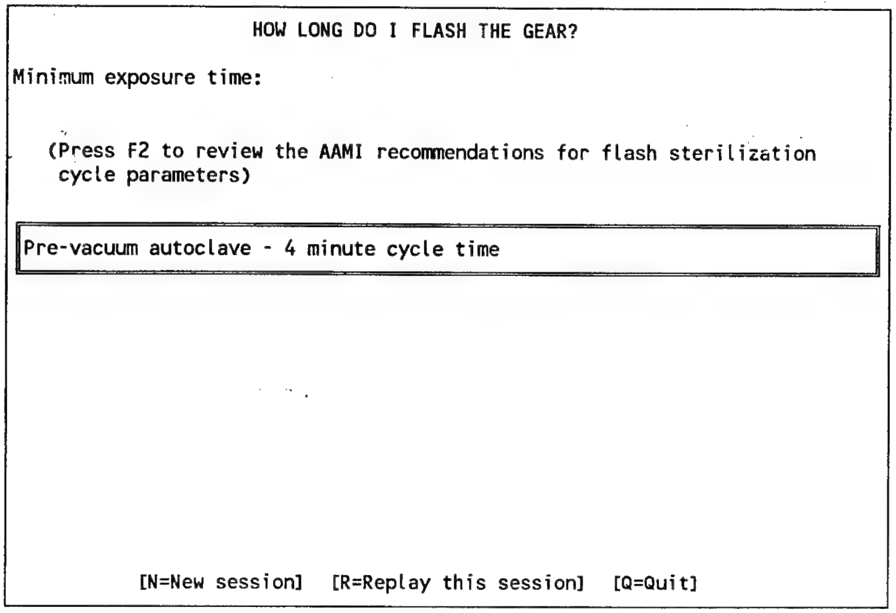


Fig. 10. Advice screen

little, test a little is based on a repeated validation testing of the evolving system. Each time the partially completed system is run to test the knowledge in the program, all aspects of the operation of the program are verified as well (Prerau 1990).

Several tools were also used to verify the initial prototype including visual verification of the graphical rule and printing session reports (see appendix A,B). While running the advisor, the cause of inaccurate advice was determined by viewing the rule with the trace window or by pressing function keys to highlight results corresponding to the advice on the rule and example screens.

The initial prototype was examined by one additional domain expert to determine the feasibility of the application and the KE approach to the problem. The Perioperative Nurse Training Course instructor examined the prototype to determine if the system could be used as a teaching tool in the course.

The full prototype was tested by three independent domain experts assigned to the Naval Hospital. To select the perioperative nurse experts, the following criteria were used: (1) significant experience in perioperative nursing, (2) currently working or teaching in the perioperative setting, and (3) recognized as an expert by subordinates, peers, and superiors (Caffrey 1994c). The domain expert's years of perioperative experience ranged from eight to fifteen years. One nurse was also certified by the NCB:PNI.

Validation participants were initially provided an overview of expert systems and the scope of the project. They were asked to use the system as if they were novice perioperative nurses and to follow the system's progress by noting the requested inputs and evaluating the solutions (Tuthill 1990).

Four areas were listed on the validation form: face validity, content validity, interface, and outputs (Tuthill 1990). Each area was rated using a five-point Likert scale: 5 = strongly agree, 4 = agree, 3 = neither agree or disagree, 2 = disagree, 1 = strongly disagree. Information

regarding subspecialty code and years of perioperative experience was also collected on the validation form (appendix C).

A total score for each area was obtained by summing the ratings. The sum was divided by the total number of experts to rate the mean agreement in each area.

CHAPTER 3

RESULTS

Initial testing confirmed the feasibility of the application and the knowledge engineer's approach to the problem. Also, the usability of the data entry interface and accuracy of the flash sterilization outputs were validated.

As shown in table 2, the experts rated all areas included on the validation form as either four or five indicating that the perioperative nurse experts agreed that the full prototype system is valid. The mean scores indicated that the expert panel strongly agreed that the system will assist in the cognitive learning process of the perioperative nurse, models the knowledge of an expert perioperative nurse, and provides accurate advice. Although they agreed that the system is easy to understand and use, two members provided suggestions to simplify the user interface. The suggestions included (1) designing the data entry form so that the user could arrow up to the previous data entry field, (2) decreasing the number of keystrokes needed to select a choice from the hypertext screen and then move to the next data entry field, and (3) coding yes or no values as single character choices.

TABLE 2

DESCRIPTIVE STATISTICS

Area	Expert 1	Expert 2	Expert 3	Mean
Face validity	5	5	4	4.67
Content validity	5	5	4	4.67
Interface	4	4	4	4.00
Outputs	5	5	5	5.00

CHAPTER 4

DISCUSSION

Validation of the initial and full prototypes demonstrated that expert perioperative knowledge can be defined and validated by independent experts. It also lead to several important interface design considerations.

The simplest and most error-free way for a user to enter data into the advisor is with the default menus that the expert system shell provides. Data entry methods are selected when (1) the user prefers to enter much data on one screen, and (2) to allow the user to progress from a novice using menus to an expert filling data entry forms. Putting all of the factors in memo or factor text also allows the user to quickly enter any information that is known. When constructing data entry forms, the KE must carefully prompt the user to enter correct information. However, the user can go back and to enter or edit data by pressing [Home], [Pg Up], or the arrow key. After accepting the data entry screen, more explicit questions will come up for fields where data was not entered (Thomas and Hapgood 1992).

For perioperative nursing, the data entry method allowed the KE to outline the expert's reasoning process for each KBM on one to two screens. This permits the user to

review the expert's reasoning process in one glance. Selections for the queries were presented in hypertext windows activated by pressing the [F10] key. The user can select and enter data for each data entry field and then arrow down or [enter] to move to the next field. If more information was needed, the user was instructed to press [End] to by-pass all remaining fields and move into the menu-based interview session. The default menus included a function key to request additional information.

The edit features and keystrokes needed to select choices frustrated the perioperative experts. Unfortunately the features are inherent to the system and cannot be modified. Prompting for yes or no selections with single characters can be added to the queries on the data entry screen. The user would then select from the choices on the hypertext screen or type Y or N and [enter]. Retesting of the full prototype will confirm if the revised user interface would be easier to understand and use.

Testing of the system by novice perioperative nurses remains outstanding. Questions that remain to be answered include: (1) what data entry design will be most effective for novices and experts, (2) will the system be effective in teaching the cognitive aspect of perioperative care, (3) will the perioperative experts and educators be able to maintain and update the system, and (4) could expert systems

reduce the direct teaching time required when orientating novice perioperative nurses to each surgical service.

The expert panel also brought attention to using the system in conjunction with the Competency Based Orientation and Performance Appraisals. In addition, the use of the system by experienced nurses was also supported. The panel suggested that experienced nurses may benefit by being exposed to alternate interventions for problem resolution.

CHAPTER 5

CONCLUSIONS

This project demonstrated that a prototype expert system that captures expert knowledge and provides a model of the expert's reasoning process can be developed and validated for perioperative nursing. It also suggests that expert systems could provide a solution to the problems created by the shortage of experienced perioperative nurses: an expert system (ES) would provide a means of capturing and preserving the knowledge of retiring expert perioperative nurses.

Also, a production system, once developed and validated, could provide an alternate teaching tool for Perioperative Nurse Training Course. It would assist in the cognitive learning process of the novice perioperative nurse. While consulting the system, the novices would improve their reasoning skills by modeling the decision style of experts (Probst and Rush 1990).

Additionally, the ES would provide a conveniently available source of knowledge. The information can be made available to anyone that has access to a PC. Consultation could take place in a non-threatening manner at a convenient

time for the user (Probst and Rush 1990; Fonteyn and Grobe 1994).

Finally, the expert system would benefit the patient by preparing the novice and experienced nurse to identify potential problems more quickly, make more appropriate clinical decisions, and choose more successful interventions for problem resolution. The benefits would result in improved quality of care and would increase the likelihood of positive patient outcomes (Fonteyn and Grobe 1994).

APPENDIX A

DATA ENTRY SESSION REPORT

HOW LONG DO I FLASH THE GEAR?

This knowledge base recommends the action for you to take when sterilizing items at 270F in gravity displacement or pre-vacuum autoclaves. If both types of autoclaves are available, the advisor will recommend the best autoclave to use in an urgent situation.

Enter these parameters   Press F10 for choices

Type of autoclave:	both
Contents of load:	multi
Is the gear required	ASAP

*continue

==> continue

(Press F2 to review the AAMI recommendations for flash sterilization cycle parameters)

Pre-vacuum - 4 minute cycle time

End of Session Report for Knowledge Base FLASH3   05/21/1995

APPENDIX B

MENU-BASED SESSION REPORT

HOW LONG DO I FLASH THE GEAR?

This knowledge base recommends the action for you to take when sterilizing items at 270F in gravity displacement or pre-vacuum autoclaves. If both types of autoclaves are available, the advisor will recommend the best autoclave to use in an urgent situation.

Enter these parameters

	Press F10 for choices
Type of autoclave:	??AUTOCLAVE
Contents of load:	??LOAD
Is the gear required	??REQUIRED

* continue

==> continue

What type of flash autoclave is available?

*gravity displacement
*pre-vacuum
*both

==> both

What is the content of the load to be sterilized?

*single item
*multiple items
*porous item or items
*item or items with lumens

==> multiple items

When is the gear required?

*for the next case
*ASAP

==> ASAP

(Press F2 to review the AAMI recommendations for flash sterilization cycle parameters)

Pre-vacuum autoclave - 4 minute cycle time

End of Session Report for Knowledge Base FLASH3 05/21/1995

APPENDIX C

EXPERT SYSTEM VALIDATION FORM
U. S. ARMY-BAYLOR UNIVERSITY OPERATING ROOM ADVISOR
VERSION 1.1

This prototype system incorporates factual and heuristic knowledge and was designed to assist in the cognitive learning process of the novice perioperative nurse. The prototype represents only a subset of a complete application that could be built for perioperative nursing. Please use the system as if your were a novice perioperative nurse. Note the system's requested inputs and evaluate the solutions.

1. Date: [ ]

2. Your subspecialty code: [ ]

3. Your perioperative experience: [ ] years

Please rate your level of agreement	**Strongly agree**				**Strongly disagree**
4. Face validity: does the system seem to do what is was designed to do?	5	4	3	2	1
5. Content validity: does the system model the knowledge of an expert perioperative nurse?	5	4	3	2	1
6. Interface: does the user find the system easy to understand and use?	5	4	3	2	1
7. Outputs: does the system provide accurate advice?	5	4	3	2	1

8. COMMENTS/RECOMMENDATIONS (include errors found in the knowledge and additional modules to be developed for perioperative nursing)

REFERENCE LIST

AICorp, Inc. 1990. 1stClass Expert System for the Easy Development and Delivery of Expert Systems.

Association of Operating Room Nurses, Inc. 1995. 1995 Standards and Recommended Practices. Denver: Association of Operating Room Nurses, Inc.

Association of Operating Room Nurses, Inc. 1994. 1994 Standards and Recommended Practices. Denver: Association of Operating Room Nurses, Inc.

Avery, L. H. 1994. Bylaws amendments, member at large delegates, redefinition of perioperative nursing top business issues this year. AORN 59, no. 6 (June): 1167-91.

Beeby, B., Nurse Corps Career Plans Officer. 1994. Interview by author, 14 October, Jacksonville, FL. Phone conversation. BUMED (OONCB3), Washington, D.C.

Benner, P., and C. Tanner. 1987. How expert nurses use intuition. American Journal of Nursing 87 (January): 23-31.

Bradburn, C., J. Zeleznikow, and A. Adams. 1993. FLORENCE: synthesis of case-based and model-based reasoning in a nursing care planning system. Computers in Nursing 11, no. 1 (January-February): 20-24.

Bureau of Medicine and Surgery. 1992. BUMEDINST 1214.1: Assignment of Medical Department Officer Subspecialty Codes. Washington, D.C.: Bureau of Medicine and Surgery.

Caffrey, G. J. 1992. A message from the perioperative specialty advisor. Navy Nurse Corps Director's Update 1, no. 3 (August): 14-15.

________. 1994a. Specialty advisor notes: perioperative nursing community. Navy Nurse Corps Director's Update 3, no. 1 (January): 8-9.

_________. 1994b. Specialty advisor notes: perioperative nursing community. Navy Nurse Corps Director's Update 3, no. 2 (August): 8.

_________, Perioperative Specialty Advisor. 1994c. Interview by author, 21 October, Jacksonville, FL. Phone conversation. National Naval Medical Center, Bethesda, MD.

Carrico, M. A., J. E. Girard, J. P. Jones. 1989. Building Knowledge Systems. Developing & Managing Rule-Based Applications. New York: McGraw-Hill Book Company.

Chang, B. L., and M. Hirsch. 1991. Knowledge acquisition and knowledge representation in a rule-based expert system. Computers in Nursing 9, no. 5 (September-October): 174-78.

Fonteyn, M. E., and S. J. Grobe. 1994. Expert system development in nursing: implications for critical care nursing practice. Heart & Lung 23, no. 1 (January-February): 80-87.

Gevarter, W. B. 1990. The nature and evaluation of commercial expert system building tools. Computer (May 1987): 34-51; reprint, Los Alamitos, CA: IEEE Computer Society Press (page references are to reprint edition).

Harding, W. T., R. T. Redmond, M. C. Corley. 1993. Loading a nursing expert system from text: a case study. Computers in Nursing 11, no. 6 (November-December): 277-81.

Hiatt, K. 1993. Nurse Corps Plans and Analysis. Navy Nurse Corps Director's Update 2, no. 3 (August): 10.

_________. 1994a. Nurse Corps Plans and Analysis. Navy Nurse Corps Director's Update 3, no. 1 (January): 47.

_________, Assistant for Nurse Corps Plans and Analysis. 1994b. Interview by author, 12 September, Jacksonville, FL. Phone conversation. BUMED (OONCB2), Washington, D.C.

Ignizio, J. P. 1991. Introduction to Expert Systems. The Development and Implementation of Rule-Based Expert Systems. New York: McGraw-Hill, Inc.

Jones, B. T. 1991. Building nursing expert systems using automated rule induction. Computers in Nursing 9, no. 2 (March-April): 52-60.

Koch, B., and J. McGovern. 1993. EXTEND: a prototype expert system for teaching nursing diagnosis. Computers in Nursing 11, no. 1 (January-February): 35-41.

Lappe, J. M., B. Dixon, L. Lazure, P. Nilsson, J. Thielen, J. Norris. 1990. Nursing education application of a computerized nursing expert system. Journal of Nursing Education 29, no. 6 (June): 244-48.

Medsker, L., and J. Liebowitz. 1994. Design and Development of Expert Systems and Neural Networks. New York: MacMillan College Publishing Company.

Mundy, C. M., and D. M. Gilcreast. 1994. Organizational Downsizing and Closure in Two U.S. Army Hospitals. Military Medicine 159, no. 3 (March): 224-226.

Petrucci, K. E., and P. R. Petrucci. 1991. Expert systems and nursing. Nursing Economics 9, no. 3 (May-June): 188-90.

Petrucci, K. E., A. Jacox, K. McCormick, P. Parks, K. Kjerulff, B. Baldwin, P. Petrucci. 1992. Evaluating the appropriateness of a nurse expert system's patient assessment. Computers in Nursing 10, no. 6 (November-December): 243-49.

Prerau, D. S. 1990. Developing and Managing Expert Systems. Reading, MA: Addison-Wesley Publishing Company.

Probst, C. L., and J. Rush. 1990. The CAREPLAN knowledge base. A prototype expert system for postpartum nursing care. Computers in Nursing 8, no. 5 (September-October): 206-13.

Thiele, J. E., J. Holloway, D. Murphy, J. Pendarvis, and M. Stucky. 1991. Perceived and actual decision making by novice baccalaureate students. Western Journal of Nursing Research 13, no. 5 (October): 616-26.

Thomas, W., and W. Hapgood. 1992. 1st-Class Reference Manual. Palo Alto, CA: Trinzic Corporation.

Thompson, C. B., S. A. Ryan, H. Kitzman. 1990. Expertise: the basis for expert system development. Advances in Nursing Science 13, no. 2 (December): 1-10.

Turbain, E. 1993. Decision Support Systems and Expert Systems. New York: MacMillan Publishing Company.

Turner, P., Nurse Corps Personnel Plans Analyst. 1994. Interviewed by author, 18 October, Jacksonville, FL. Electronic mail. BUMED (524), Washington D.C.

Tuthill, G. S. 1990. Knowledge Engineering: Concepts and Practices for Knowledge-Based Systems. Blue Ridge Summit, PA: Tab Books.

Woolery, L. 1990. Expert nurses and expert systems. Research and development issues. Computers in Nursing 8, no. 1 (January-February): 23-28.

Woolley, N. 1991. A computerized assessment for clinical care. An expert system for pressure sore management. Professional Nurse 6, no. 11 (August): 632-38.